HYDROLOGIC MODELING SYSTEM FOR NORTHERN NECK PLANNING DISTRICT

Coastal Zone Management Program

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Table of Contents

List of Figures

HYDROLOGIC MODELING SYSTEM FOR NORTHERN NECK PLANNING DISTRICT

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1.0 INTRODUCTION

1.1 Background

In April 1989, the Information Support Systems Laboratory (ISSL), Department Agricultural Engineering, Virginia Tech entered into a contract with the Northern Neck Planning District Commission No. 17 to initiate the first phase of a multi-phased program for developing a comprehensive water resource management system (CWRMS) for the Northern Neck. The goal of this initiative is to provide water management tools with sufficient functionality to identify areas appropriate for local planning and regulatory efforts and to model, assess and evaluate proposed projects and landuse activities. The basic components of the proposed "tool-kit" will include the following:

- Information Support System (GIS/Relational Data base/Table Lists, ect);
- Hydrologic models (quantity and quality);
- GIS/Relational Database/Model Interface(s);
- Hardware Platform; and
- Personnel Support.

Although the above components are multi-dimensional, a significant beginning towards building a CWRMS currently exists in the Northern Neck. For example, ISSL with contracts from the Department of Conservation and Recreation-Division Soil and Water Conservation (DCR-DSWC) has developed and/or is participating in the following programs significant to improved management of water resources in the Northern Neck Planning District:

- A digital Geographic Database from VirGIS contains base data layers for soil type and soil characteristics; elevation; surface flow drainage; landuse (cropland and pastureland); hydrologic units; and political boundaries (counties/cities).
- A PC-based GIS system for Richmond County which includes additional data layers for wetlands (tidal and nontidal); watersheds (50-150 acres); flood plain; property boundaries; stream order; woodland; additional categories of landuse such as low density residential, commercial, etc; transportation; coastal zone erosion rates; historic sites; wildlife habitat; and Baylor grounds.
- A comprehensive surface and groundwater monitoring program (quantity and quality) in the upper reaches of Nomini Creek, which includes nutrient and pesticide concentrations; flow rates and volumes; rainfall (rates, volume, distribution and quality); comprehensive land use (including tillage and nutrient and pesticide tracking on all land parcels within the study area); pesticide tracking on all land parcels within the study area); pesticide and nutrient movement through the vadose zone; and biological monitoring.
- Sediment and nutrient screening models for identifying expected annual sediment, nitrogen and phosphorus stream loading rates from agricultural land areas.

1.2 Objectives

This report focuses on the development of a Hydrologic Modeling System (HMS) for assessing the impact of development and other land use changes on the quality of surface water entering receiving waters. Other programs are planned that will address ground water and interactions between surface and groundwater flow systems. The objectives of this project were:

- To port the Finite Element Storm Hydrologic Model (FESHM) to a PC-based environment for use to simulate surface flows and sediment detachment and transport; and
- To design, develop and implement a user friendly interface using Geographic Information System (GIS) Technology to assist with data compilation and display of simulation results.

To accomplish the above objectives the workscope was divided into the following general tasks:

1. Review of FESHM and organizing I/O functionality;

2. Porting mainframe version of FESHM to PC-base environment;
3. Developing software to automate the selection of model parameters;
4. Designing and developing a menu/prompt system for program navigation;
5. Designing and developing a procedure for conducting what-if-scenarios;
6. Linkage of all components for simulation of streamflow hydrographs.

The report is organized into sectinns reflecting the tasks outline above. Section 2.0 gives a summary of mathematical modeling and a brief review of concepts and functionality contained in the FESHM. The Hydrologic Modeling System is described in Section 3.0. Specific emphasis is placed on tasks 3 - 4 listed above. The application of the package for simulation of streamflow hydrographs also is illustrated in Section 3.3.

2.0 MATHEMATICAL MODELING/FINITE ELEMENT STORM HYDROGRAPH MODEL

2.1 Mathematical Modeling

Modeling is a technique for analyzing large complicated systems by constructing smaller systems that reflect only the characteristics of interest. With the rapid development of computers and computer technology during the past thirty years, it has become possible to model the hydrologic processes of a watershed as a series of interacting equations. These developments, which are often referred to as computer-based mathematical watershed models, have generally been derived using either the 'systems' approach or the 'parametric' approach. In the systems approach the watershed is conceptualized as a black box in which rainfall input and streamflow output are related only through decision theory, systems analysis or operations research methods that need have no direct relation to the physical watershed system.

In the parametric approach, the rainfall input is normally operated on by empirical or deterministic relationships that attempt to describe specific physical processes such as infiltration, evaporation, overland flow, and channel flow. Thus each process is related to the streamflow by some function of the related watershed parameter. A conceptual framework is first developed to link all the known significant system components. The components then are described by either theoretical or empirical equations. In this way the individual parameters, at least in concept, have physical meaning and can be studied by laboratory and/or field experiments.

The use of modeling and simulation is increasingly becoming an acceptable tool to describe hydrologic activities within a given drainage system. Recent concern for environmental pollution with specific emphasis on improving the quality of the Chesapeake Bay, has provided renewed interest for using modeling techniques to relate land use practices to downstream water quality. Since pollutant transport is predominantly a hydrologic process, there has been a major effort to interface material transport submodels with existing parametric hydrologic models. This effort has brought to light, however, an awareness that the values assigned to hydrologic parameters of a watershed vary widely within a single watershed. Thus, it is necessary to consider the spatial characteristics of the watershed such as soil boundaries, local topography, and land use, to account for the resulting water quality.

Since nonpoint pollution is tied so closely to the hydrologic system, any effort toward controlling it must consider the soil-water interface and the hydrologic transport system. Here hydrologic modeling can have its greatest benefit. The hydrologic model can be used to reduce the very complex natural watershed system to a more easily observable system. The model user could then create a rational plan of attack for abatement of nonpoint pollution. First, it would be possible to isolate areas of the watershed where critical pollutional potential exists. Then the transport system could be examined to determine whether pollution arising at the specified location reaches the receiving stream, lake or estuary or is deposited or transformed en route. Finally, the modeler could test pollution abatement schemes to be sure that the public receives the best possible pollution abatement for each dollar spent.

2.2 Finite Element Storm Hydrograph Model

The Finite Element Storm Hydrograph Model (FESHM) was selected for the hydrologic model sub-system because it was originally developed for the specific purpose of evaluating the impact of landuse change on flow regimes. The model structure is based on the concept that a watershed (or drainage area) can be sub-divided into smaller units that are assumed hydrologically homogeneous and that the flow responses from the individual units can be integrated to describe the watershed response. Conceptually, flows can be traced through the system and the influence of individual subsets determined.

The most significant advantage of this concept is that many aspects of the natural watershed system can be incorporated to answer specific questions about the hydrologic response due to perturbation. When the mathematical system is properly constructed it can be used with data at varying levels of resolution to analyze the water quantity and/or quality response from single farm units, entire basins, or the effect of single farm units on a larger watershed for a given rainfall occurrence.

The finite element numerical method was used as the basis for the development of a spatially responsive model structure. A fundamental concept in finite element analysis is that most complex systems can be sub-divided to form some minimal number of subsets, that can be analyzed independently and the results collected to form the total system response. This concept provides a ready mechanisms for routing surface flow, given a reliable estimate of rainfall excess and reinfiltration.

The above procedure provides for tremendous flexibility for the incorporation of data for the purpose of generating synthetic hydrographs. All available data can be incorporated so that the spatiotemporal integrity of the area can be maintained. A new model structure is not necessary to do either micro- or macro-level modeling.

2.3 Spatial Variability

Spatial variability is incorporated into FESHM to improve estimates of the spatiotemporal variations inherent in rainfall excess and the time distribution of runoff. Two discretization structures were developed to represent (1) the spatial and temporal distribution of rainfall excess and (2) the routing of the excess water through the drainage system.

2.3.1 Rainfall Excess

To improve estimates of rainfall excess FESHM utilizes a procedure that considers the spatial variability in soils and the spatiotemporal variability of landuse. Basically, the area is subdivided into unique combinations based on soil mapping units and landuse data. The combinations are defined as Hydrologic Response Units (HRUs). The rainfall excess (i.e. water available for routing to a stream) for each HRU is calculated by a soil moisture algorithm which uses an empirical approximation to describe the infiltration process in lieu of the partial differential equations of vertical unsaturated flow because infiltration recovery can be readily determined and the procedure has been demonstrated to provide acceptable estimates of excess rainfall.

2.3.2 Flow Routing

To provide the best spatiotemporal representation of factors that effect flow routing, the watershed is subdivided into finite-sized elements. Watersheds (or drainage areas) are sub-divided into sub-watersheds based on the stream drainage network. Each sub-watershed then is sub-divided into overland flow strips. Each sub-watershed must have a minimum of two flow strips (left and right of the stream). Each overland flow strip, also, can be further sub-divided into a series of elements to accommodate changes in the surface topography. For the situation where the overland flow strip is not sub-divided then it is defined as an element, which represents the basic unit in the sub-division.

The sub-watersheds (tributary drainage systems) can be easily identified from a contour map. The sub-watersheds then are separated into unit source drainage areas and the strips into finite-sized elements as required for a specific analysis. An automated procedure for the delineation of watershed boundaries is described in Section 3.2.

The division of the sub-watershed into overland flow strips and/or elements provides additional flexibility for incorporating spatial variation. At this level, the modeler has the option to refine the discretization of elements to the configuration that will provide the best solution to his problem. For example, if the modeler must determine the fate of nutrient applications on a particular crop, then the field or region containing the crop must be divided into elements so that flows emanating from the corn field can be separated from those originating from adjacent areas.

2.3.3 Issues in Defining Spatial Variability

The first prerequisite to the application of a spatially responsive modeling system (eg FESHM) requires the creation of a data base that will adequately represent the spatiotemporal character of the area being investigated. A number of watershed characteristics vary spatiotemporally and their variation must be described for proper evaluation of the impact of each on the problem being addressed.

The distribution of landuse is particularly important since the proximity of a given cropping system to well defined drainage channels will play a significant role in the magnitude of sediment and nutrients entering the receiving stream. The orientation of agricultural cropping systems with respect to slope and drainage channels can significantly alter the hydrologic response of the area. This is particularly true for small storm events. The effect of landuse change on storm water runoff, however, tends to decrease as storm size increases.

Surface retention storage varies significantly from one area to another. Values exceeding 1.5 inches may not be uncommon. The effect of such areas on storm water runoff and the associated impact on the movement and concentration of agricultural nutrients can be significant.

Soils vary greatly in their hydraulic characteristics, therefore, the hydrologic response, also, often varies greatly. These variations are tempered somewhat by soil cover conditions, landuse patterns and management practices. Wet land areas, localized channelization, drainage projects, farm ponds, etc., can all impact the quantity and quality of water moved from a specific area.

The preparation of a data base to include spatiotemporal variations is perhaps the most time-consuming and often challenging task that confronts a modeler (user). As previously noted FESHM is structured to provide the user with a high degree of flexibility for the inclusion of spatial detail to provide answers to a specific question. The major task that faces the user, however, is deciding on the level of discretization (i.e., spatial variability) that must be included to get a reliable simulation at the desired level of predictability (accuracy). This problem is further complicated because of the general lack of objective criteria to define precisely what detail is necessary for most applications. We have not, unfortunately, been able to define an exact line of demarcation. No single set of criteria appears to be usable. Rather, the separation point is a function of an incredibly complex set of factors, which not only includes physical properties of the drainage system but economic constraints.

2.4 Input Data Requirements for FESHM

The input data requirements for FESHM can be grouped into the following categories:

1. **Control options** -- Group 1 includes instructions for type of output listings and the time interval for discharge data listed in output.
2. **Rainfall Distribution** -- Group 2 includes data for number of raingages in the watershed, duration of storm event in hours, duration of the simulation, time interval of rainfall in seconds, antecedent soil moisture factor for the watershed, storm date (month, day, year, hour and minute), and rainfall volumes per selected time interval. Also included in this group, are factors used to provide a seasonal adjustment to infiltration potential.
3. **Element/HRU cross-reference** -- Group 3 includes data to assign HRUs to elements with aerial extent. These data are used by FESHM to calculate weighted rainfall excess (ie an effective HRU).
4. **Land use and HRU descriptors** -- Group 4 includes data for FESHM parameters relating to HRUs. The data are included in two tables for land use characteristics and HRU parameters, respectively.
5. **Computation time and index for flow routing** -- Group 5 includes the time increments for routing both overland and channel flows. Additionally, this group includes the connectivity for the channel flow system.
6. **Element descriptors for overland and channel flow** -- Group 6 includes length, relief, channel roughness and flow cross-section data for overland and channel elements.

3.0 HYDROLOGIC MODELING SYSTEM

The Hydrologic Modeling System is PC-based and consists of a series of modules linked via a system of menus for the purpose of simulating storm water discharge and sediment detachment and transport. The sediment detachment and transport component has not been completed. The menu navigational linkage for this segment wiil be included in the next update. A general schematic for the system configuration is given in Figure 1. The software was written using Fortran 77 and Metawindows graphics, and contains four levels of menus to provide the user access to GIS and hydrologic modeling functionality.

A review of system functionality is covered in Sections 3.1, 3.2 and 3.3. The building of FESHM compatible databases is covered in Section 3.1, which is followed by a discussion of the Map Editor in Section 3.2. Finally, in Section 3.3 navigational functionality is covered. Additionally, the use of the system to simulate discharge hydrographs is illustrated with the appropriate menu options.

3.1 Building Input Databases

As previously noted, the major difficulty with using distributed parameter hydrologic models is problems associated with preparing extensive databases that adequately reflect spatiotemporal variations that exist in watershed systems. A major effort was expended in this project to overcome many of these problems as they relate to data preparation for FESHM. The major issues involved automating the selection of topographic and soil/landuse related characteristics, keyboard entry of control instructions and designing a linkage to provide access to all components of the system within the same computing environment.

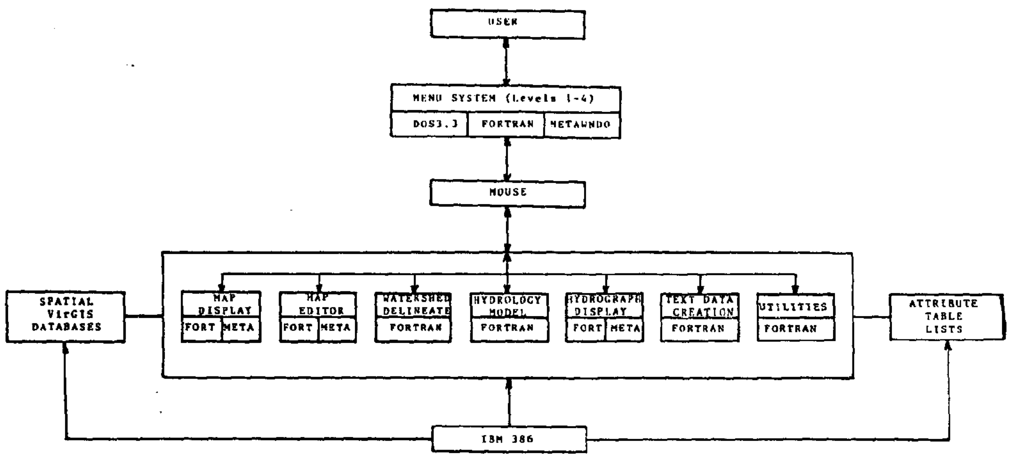

Figure 1. Schematic of Hydrologic Modeling System for Northern Neck Planning District.

The basic tasks to automate data preparation and input included the following:

- Designing standards for database creation and program access;
- Developing computer code to automate the selection of topographic characteristics required by FESHM;
- Developing computer code to automate the definition of hydrologic response units;
- Developing procedures to allow interactive entry of program control and rainfall distributions.

3.1.1 Standards

To simplify computer search for data and to improve the user interface, standards for directories and for data filenames were established to represent related program functionality.

3.1.1.1 Directories

The following directories were defined:

- **METAW**-- This directory contains pointers to Metawindow graphics and related menu software.
- **PROGRAM** -- This directory contains pointers to all Fortran programs. This package includes programs STREAM, DISCRETE, SUBSHED, HRU, EFFHRU, and FESHM. Also included are fortran procedures for system menus and prompts, and the procedures for using Metawindow graphics software.
- **DATAFILE** -- This directory contains pointers to input data required by the programs in directory **PROGRAM**. The input data generally include VirGIS map data for soil type, landuse, elevation, stream network and stream order, user created VirGIS-formatted map data, attribute lists (tables) and FESHM input data organized into eight-groups.
- **TEMPFILE** -- This directory contains pointers to all intermediate data files (temporary) that are created during program execution. These data files will usually be deleted after execution is completed.

3.1.1.2 File Naming Convention

The standard for naming data files was established by defining fixed file name extensions for each data type. These are presented in the following table list for VirGIS-formatted map data files, attribute lists and FESHM input data files, respectively.

3.1.1.2.1 VirGIS-formatted map data files

	Extensions	
Data type	VirGIS Map	VirGIS-formatted map
Stream network	VND	VNF
Stream order	VOD	VOF
Landuse	VLD	VLF
Soil type	VSD	VSF
Elevation	VED	VEF

3.1.1.2.2 Attribute list

	Extensions	
Data type	Package provided	User Created
Soil attribute	PAS	UAS
Landuse attribute	PLS	ULS

3.1.1.2.3 FESHM input data files

	Extensions	
Data type	VirGIS Mode	Stand-alone Mode
Group 1	G1V	G1S
Group 2	G2V	G2S
Group 3	G3V	G3S
Group 4	G4V	G4S
Group 5	G5V	G5S
Group 6	G6V	G6S
Group 7	G7V	G7S
Group 8	G8V	G8S

3.1.2 Input Data Preparation

The input data requirements for FESHM (see page 9) were reorganized into eight groups to provide better continuity between the computer code and data type that could be automated and the type that are entered interactively via the keyboard. The support provided for data automation and/or interactive data entry is discussed, by group, in Sections 3.1.2.1 through 3.1.2.8.

3.1.2.1 Data Group 1 -- Output Control Options

The output control options provides for selective listing of output. The selection of appropriate output options is accomplished by responding to prompts through keyboard. The options supported include following:

- List HRU attributes;
- List rainfall data;
- Time interval for listing overland flow rates (seconds);
- Time interval for listing Channel flow rates (seconds);
- Nodes where the simulation results are to be listed; and
- The title of simulation run.

3.1.2.2 Data Group 2 -- Rainfall Distribution/Seasonal Infiltration Adjustment Factors

3.1.2.2.1 Rainfall Distribution

This group of data is not currently included in the VirGIS database. the following two options, therefore, are provided for determining the rainfall distribution.

- Obtain from recorded rainfall record; or
- Obtain from design storm criteria.

3.2.2.1.1 Recorded rainfall record

The recorded rainfall distribution can be entered either interactively via the keyboard or by entering a datafile created previously. Only the interactive option is currently supported by the HMS package. The second option is planned at a later date when rainfall distribution data are included in the VirGIS database.

The following information is requested for entry via the keyboard:

- Number of rainfall gages for which data are being included (usually one);
- Duration of rainfall (storm) in hours;
- Duration of simulation (i.e. length of storm simulation) in hours;
- Time interval of rainfall records (The intervals must be equal. The interval usually chosen is 15 minutes);
- Antecedent soil moisture condition for the watershed as a fraction of field capacity;
- Starting time of storm event (hour and minute);
- Month in which storm began;
- Day in which the storm began;
- Year in which storm began; and
- Rainfall data by time interval.

3.2.1.1.2 Design storm criteria

This option is not currently supported by HMS but will involve selecting a design storm (eg rainfall expected to occur over a 24 hour period once every 10 years) and then generating a FESHM compatible rainfall distribution with appropriate computer code. This option is planned for the next update of HMS.

3.1.2.2.2 Infiltration Adjustment Factors

To accommodate the variation of infiltration with season, FESHM uses a monthly step function to index variation. Options are provided to select system default values or to enter modifications via the keyboard.

3.1.2.3 Data Group 3 -- Element/HRU Cross-Reference

In general the geometry of HRUs created by program HRU (see Section 3.1.2.4) do not correspond to the element boundaries (sub-watersheds) defined by program SUBSHED (see Section 3.1.2.6). Since routing in FESHM is based on the element geometry, different HRU types within an element must be combined to provide an effective HRU, which is assumed to represent the soil-landuse characteristics for the element. Program EFFHRU was developed to create an Element/HRU cross-reference table. This table also includes the fractional aerial coverage that each HRU type occupied within a given element. These data are used by FESHM to determine effective (or weighted) parameters for each HRU.

3.1.2.4 Data Group 4 -- HRU Attribute List

A Fortran program HRU was developed to overlay map data themes for soil type and landuse and to uniquely define all landuse-combinations (that is HRUs as previously defined). Each HRU is assigned a numeric code beginning with one for the first occurrence. The maximum number of HRUs is equivalent to the number of soil types multiplied by the number of landuse types. For a landuse data layer containing three basic landuse types, for example crop land, pasture land and non-agricultural land and a soil

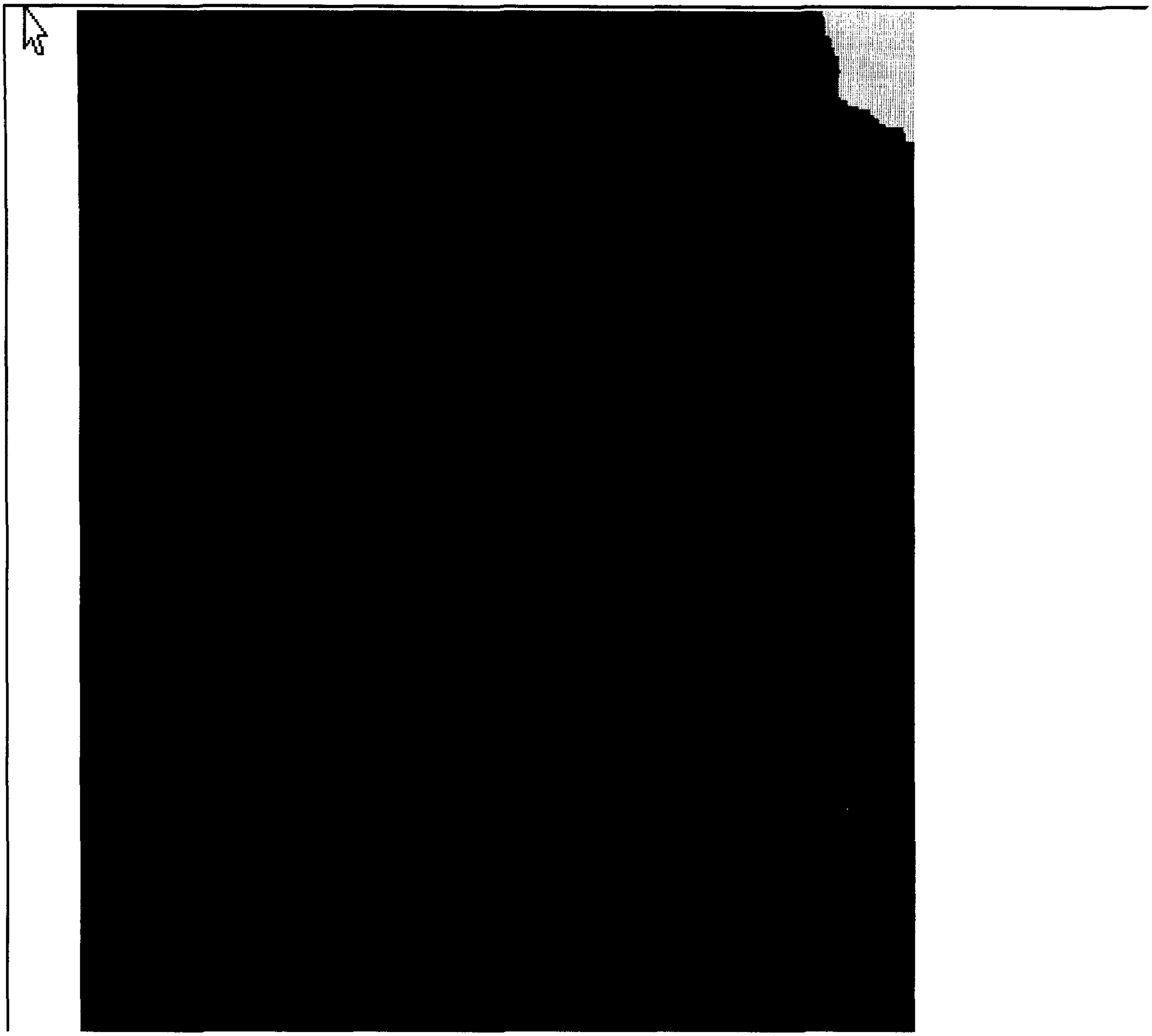

Figure 2. Landuse theme for selected segment of Haynesville quadrangle, Richmond County, Virginia

Figure 3. Soil type theme for selected segment of Haynesville quadrangle, Richmond County, Virginia

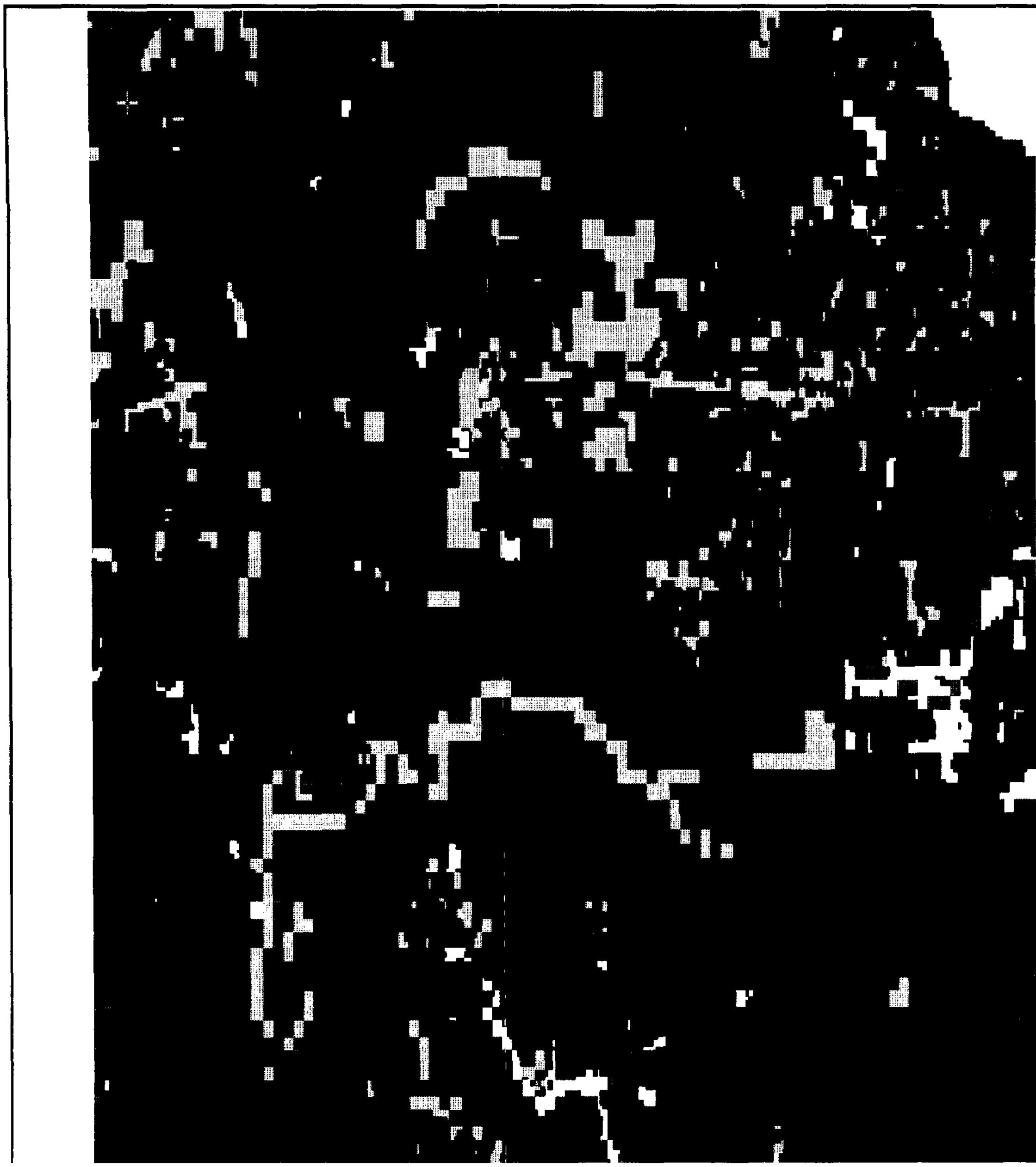

Figure 4. Hydrologic Response Units theme, which was derived by combining landuse (Figure 2) and soil type (Figure 3)

type data layer containing 27 soil types, 71 unique HRUs are possible. A typical example of the process is illustrated with Figures 2, 3, and 4. Figure 4 represents all combinations resulting from overlaying landuse (Figure 2) and soil type (Figure 3).

3.2.4.1 Generation of Landuse/Soil Type Attribute List

An automated procedure for the selection and building of this database is not currently supported by HMS. For the current application, attribute lists have been prepared for each landuse and soil type category existing the VirGIS database for Richmond County, Virginia. Other type (i.e. soils and /or landuse) can be entered using the Map Editor (Section 3.2).

The landuse attribute list contains the following characteristics for each landuse type:

- Landuse code;
- Landuse type;
- Value of A in Holtan's infiltration equation;
- Potential depression storage;
- Roughness coefficients in Manning's equation;
- USLE cover factor; and
- USLE practice factor.

The soil type attribute list contains the following characteristics for each soil type:

- Soil type index code (numeric);
- Soil type (alphanumeric);
- Potential plant available water;

- Potential gravitational water;
- Final infiltration rate;
- Depth of zone of maximum hydrologic activity (usually the A-horizon);
- Soil erodibility index; and
- Slope class.

Program HRU uses the landuse and soil attribute lists to build FESHM parameters for each HRU.

3.1.2.5 Data Group 5 -- Computation Time Interval

The following computation time intervals must be provided by the user:

- Time increment for overland flow calculations; and
- Time increment for channel flow calculations.

The stability of the time-integration procedure used in the finite element solution of the partial-differential equation is dependent on the value selected for the computation interval. When the value is too large the solution is unstable (incorrect results). When the values are significantly smaller then necessary, the execution time will be excessive. Users can enter these indexes by responding to prompts through the keyboard. Typical values have been incorporated as default. Other increments can be entered via the keyboard. Error checking is provided to insure stability of the solution.

3.1.2.6 Data Group 6 -- Flow Routing

The following data are required by FESHM to route excess rainfall through the overland and channel flow system:

- **Overland element**
  - Flow length (width of element perpendicular to stream channel);
  - Relief (difference in elevation along the flow length);
  - Area; and
  - Top width at the downstream node of the element.
- **Channel element**
  - Length;
  - Relief;
  - Roughness coefficient; and
  - Top width of the down stream node of the element (for defining channel cross-section).
- **Routing connectivity**
  - For each overland element, identify location relative corresponding channel element (i.e. east or west bank/north or south bank); and
  - For each channel element, identify up-stream tributaries.

To automate the sub-division of a watershed and subsequent determinations of the above parameters, three software packages STREAM, DISCRETE and SUBSHED were developed. VirGIS map data themes for elevation, stream network and stream order also are required. An additional option which will be added in the next update of HMS will be user supplied watershed map.

3.1.2.6.1 Fortran program STREAM

Fortran program STREAM was developed to define the connectivity of stream segments from a stream-order map. In the stream-order map, streams are classified as order 1 to 6. A first-order stream is defined as a unit source drainage, that is it has no tributaries. A second-order is defined at the confluence of two first-order streams. For Richmond County, Virginia, the Rappahannock River was classified as a sixth-order stream. A typical stream-order map for a selected segment of the Haynesville quadrangle, is shown in Figure 5.

The connectivity of the stream network is determined by first raster scanning a VirGIS-formatted stream-order map row-by-row and assigning a preliminary code to each stream cell. Numeric codes are assigned to identify the order of the stream segment and a count of the number of stream segments encountered from the beginning of scanning. For example, when the 58th second-order stream is encountered then the number of second-order segments (58) and the second-order stream code (2) are concatenated to give the preliminary code 582.

After the scanning has been completed by program STREAM, the preliminary codes are sorted based on the connectivity of stream segments. A preliminary stream coding map based only on stream order, also, is created. The connectivities of the stream segments found during scanning and sorting are stored in a connectivity matrix based on the same coding scheme. A preliminary stream-coding map for a selected segment of the Haynesville quadrangle is shown in Figure 6.

3.1.2.6.2 Fortran Program DISCRETE

A Fortran program DISCRETE was developed to further discretize the stream segments to a sub-watershed level based on tributaries and confluences determined from single center-line vectors of the stream-network map (Figure 7). The discretization of streams was accomplished by vectorizing the stream center-line and borders of stream segments to form polygons which represent the stream segments in two dimensions.

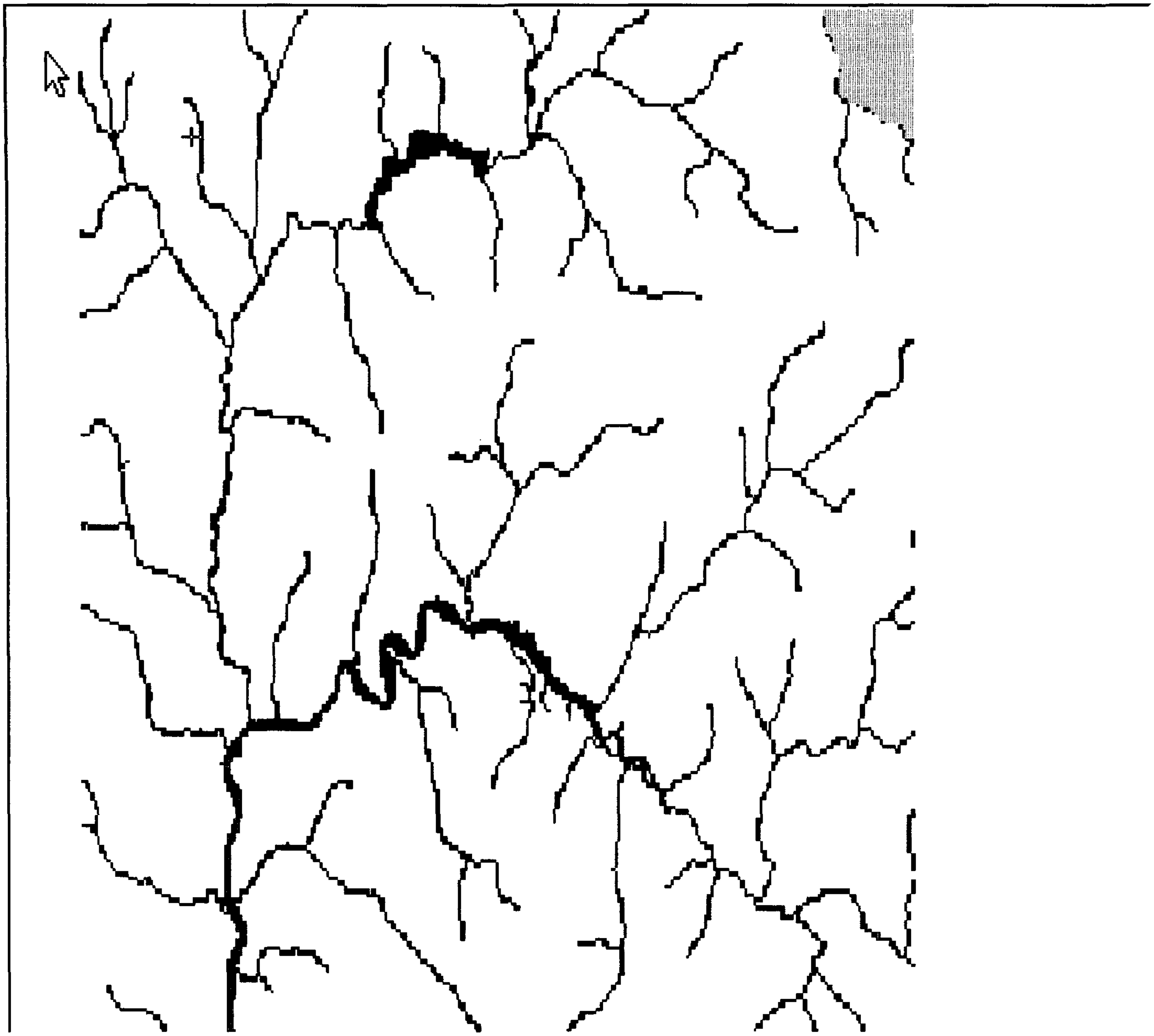

Figure 5. Stream-order theme for selected segment of Haynesville quadrangle,
Richmond County, Virginia

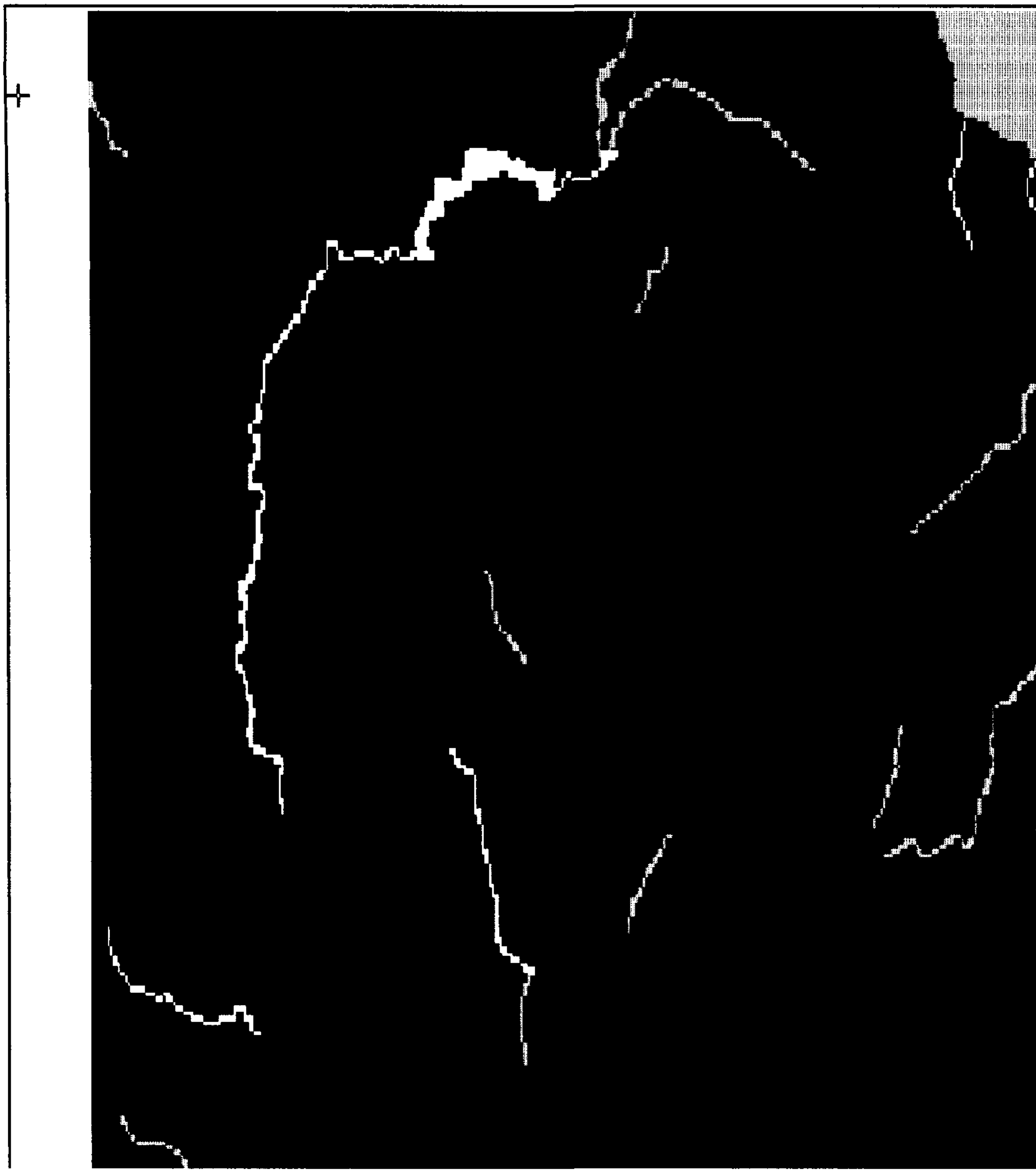

Figure 6. Preliminary stream-coding theme for selected segment of Haynesville quadrangle, Richmond County, Virginia

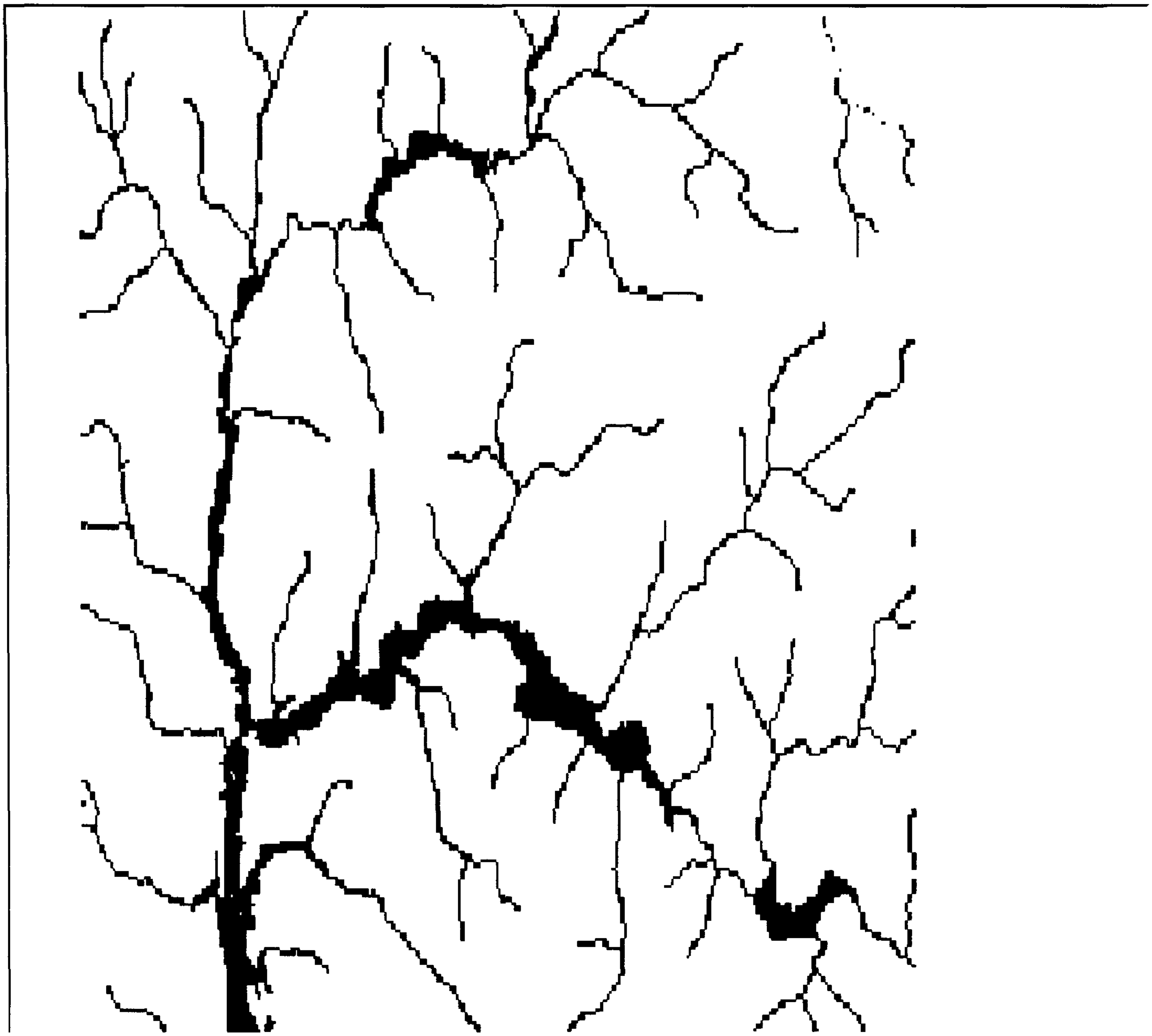

Figure 7. Stream-network theme for selected segment of Haynesville
quadrangle, Richmond County, Virginia

Each stream segment (or reach) represents the water body between two adjacent tributaries. Each stream segment then was defined as a channel element. The topographic parameters for each channel element, also, were calculated in either vector or raster mode and stored in FESHM compatible data files.

The connectivity matrix was updated during the segment-to-segment analysis. The stream coding was also updated using the same coding scheme described previously. The updated connectivity matrix was stored in a data file for later use by FESHM.

The final discretized stream-coding map for a selected segment of the Haynesville quadrangle is shown in Figure 8.

3.1.2.6.3 Fortran Program SUBSHED

In past applications with FESHM for simulating stream flows, sub-division of watersheds were made manually from topographic maps. This procedure was very tedious and became a limiting factor in the routine use of the model. A Fortran program SUBSHED, which uses VirGIS-formatted map data file for elevation and the stream-coding map described previously to automate this procedure.

A raster scanning scheme is used to examine the elevation data. For each cell, the maximum cell gradient and direction with respect to adjacent cells was calculated and the relief accumulated along the flow path until a stream cell was reached. Then the code of the stream which was defined in program DISCRETE was assigned to all the cells over which the relief was accumulated. After the scanning was completed, the cell coding was sorted to remove temporary coding that was assigned during the scanning. The temporary coding resulted because scanning was conducted only in an up-to-down order.

Figure 8. Final stream-coding theme for selected segment of Haynesville quadrangle, Richmond County, Virginia

Because the sub-watershed coding scheme was based on digital elevation models (DEMs) at a fine resolution (1/9 ha for VirGIS database) and the stream coding was based on discretization of streams up to first order, which represents the detail that the USGS quadrangle maps (1:24000 scale) can provide, the sub-watereshed delineation scheme is accurate and flexible for various selections of areas for which the simulation is conducted.

Since elevation data is the basis for sub-watershed delineations, accuracy of the elevation data is critical for the delineation of the sub-watershed boundaries. Because the delineation of sub-watershed boundaries depends on the variation of elevation (slope), accuracy is generally better for steeper topography than it is for flatter areas. After running program SUBSHED, the unidentifiable areas, i.e. those with a sink hole inside the area, represented less then 3 % of the total area. A sub-watershed map of the Haynesville quadrangle is shown in Figure 9.

The topographic parameters for each sub-watershed were also calculated by SUBSHED and stored in a data file for use by FESHM.

3.1.2.7 Data Group 7 -- Channel and Overland Element Topographic Parameters

This group of data is provided by programs DISCRETE and SUBSHED as previously described.

3.1.2.8 Data Group 8 -- Sediment Loading Input Data

Since the sediment loading component for FESHM is not completed, the support for this data group was not included.

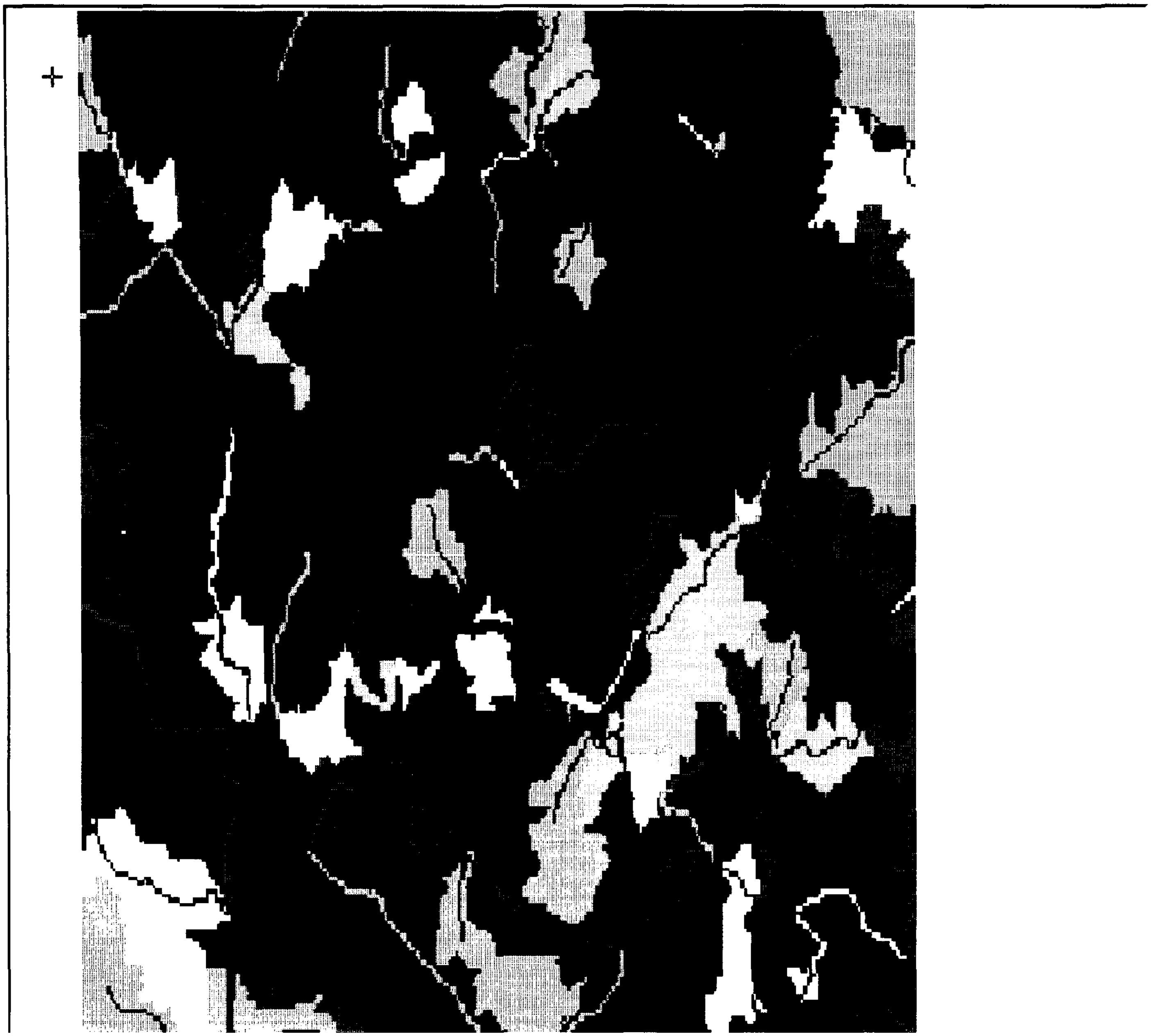

Figure 9. Sub-watershed map for selected segment of Haynesville quadrangle, Richmond County, Virginia

3.2 Map Editor

3.2.1 Functionality

The Map Editor was developed to assist the user with creating and/or editing map layers. The following functionality is supported by the Map Editor:

- For an available VirGIS database or a VirGIS-formatted database, users can analyze the impact of changed conditions (landuse, soil, stream network, etc) on surface runoff by editing one or more input data layers. This is expected to be the principal application of the Map Editor in local planning.
- If a database is not available for the study area, or the resolution of the database that is available does not meet the requirement of the analysis, then the Map Editor can be used to create a VirGIS-formatted database. This step requires limited knowledge of the VirGIS map format and no experience with ASCII file editing.
- For landuse and/or soil type maps, an option is provided to edit the ASCII coded attribute list while the map is being edited, which greatly simplifies the data preparation procedure.

3.2.2 Use of the Map Editor

To use the Map Editor the following six steps must be followed:

- The user responds to prompts for input and output data name (for example, STREAM.VND). If the user chooses to provide only the data file type (STREAM), i.e. the extension (VND) is not included, then directory **DATAFILE** is searched for all data files with file type STREAM. Only the file type having a file name extension as specified previously will be selected. The original data layers are protected from overwriting.
- A mouse is used to select the editing window. The user can repeatedly erase and re-select the window. To help locate the window, coordinates of the upper-left and lower-right corners are always displayed as the cursor moves.
- When the window is selected, the entire map will be copied to the lower-right corner of the screen, and the selected window will be enlarged and mapped in the largest possible square area (480 x 480 pixels). Grids can be attached or removed from the window by pressing the appropriate mouse control. The

transportation network, also, can be attached to the original map to assist in locating the proper window.

- During editing the user is prompted for one of the following two options:
  - **Editing-by-color** -- A total of 16 colors are supported by Metawindows through VGA. When the data range does not exceed sixteen (i.e. number of attributes), such as for landuse, stream network, and stream order maps, the user can choose editing-by-color mode. Using the mouse the user can pick up cells, erase incorrectly retrieved cells or draw an area boundary and then fill the area. The user then may choose any available value and then replace selected cells by picking up one of the color boxes. This procedure can be repeated until the editing of the selected window is completed. Figure 10 shows an editing-by-color screen.
  - **Editing-by-Values** -- For maps with the attribute values greater than 16, editing-by-values option can be used. For this option, the color boxes were replaced by value boxes. Ten values boxes with the value of 0-9 and an additional box assigned a minus sign are available in the value box area. For selecting a new value of 24, the user must pick-up the value boxes 2 and 4 in sequence, while for selecting a new value of -9 the user needs to pick-up the value box -(minus sign) and 9 in sequence. For this option, within enlarged window, cell values are displayed at the center of each cell.

Due to the limitation of the screen size, maximum row and column numbers are set for the display window to insure the visibility of cell color and cell values. The maximum row and column numbers for editing-by-color mode were set at 180 x 180 pixels, while the maximum row and column numbers for editing-by-values were set at 100 x 100 pixels.

- For landuse and soil maps, the user can edit the ASCII-code landuse attribute list or soil attribute list while editing the map. This is accomplished by pulling down an attribute list curtain. The existing attribute list is displayed on the curtain. If the user adds a new code to the map, then the attributes for the new code can be added by answering prompts via the keyboard. For example, if the user adds a fourth landuse type (for example a different crop-rotation), prompts will request all landuse attribute values needed for landuse type 4. This procedure allows editing of the attribute list without having knowledge of the attribute file format and without having previous experience in ASCII code file editing.
- After editing of a window is completed, options exist to edit another window area, to save the edited window, to edit different maps or to quit the program.

3.3 Menu System

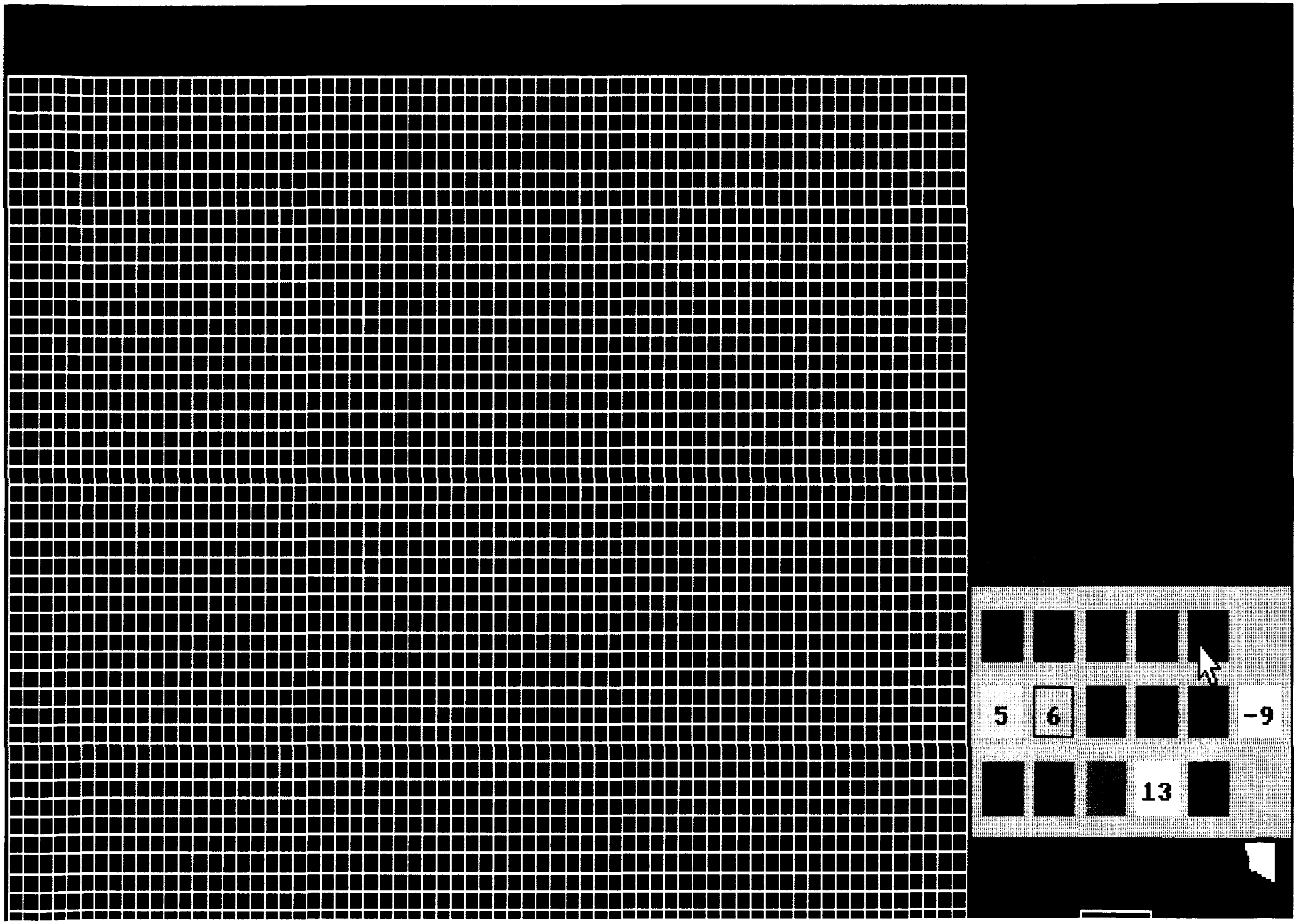

Figure 10. Screen display for editing-by-color

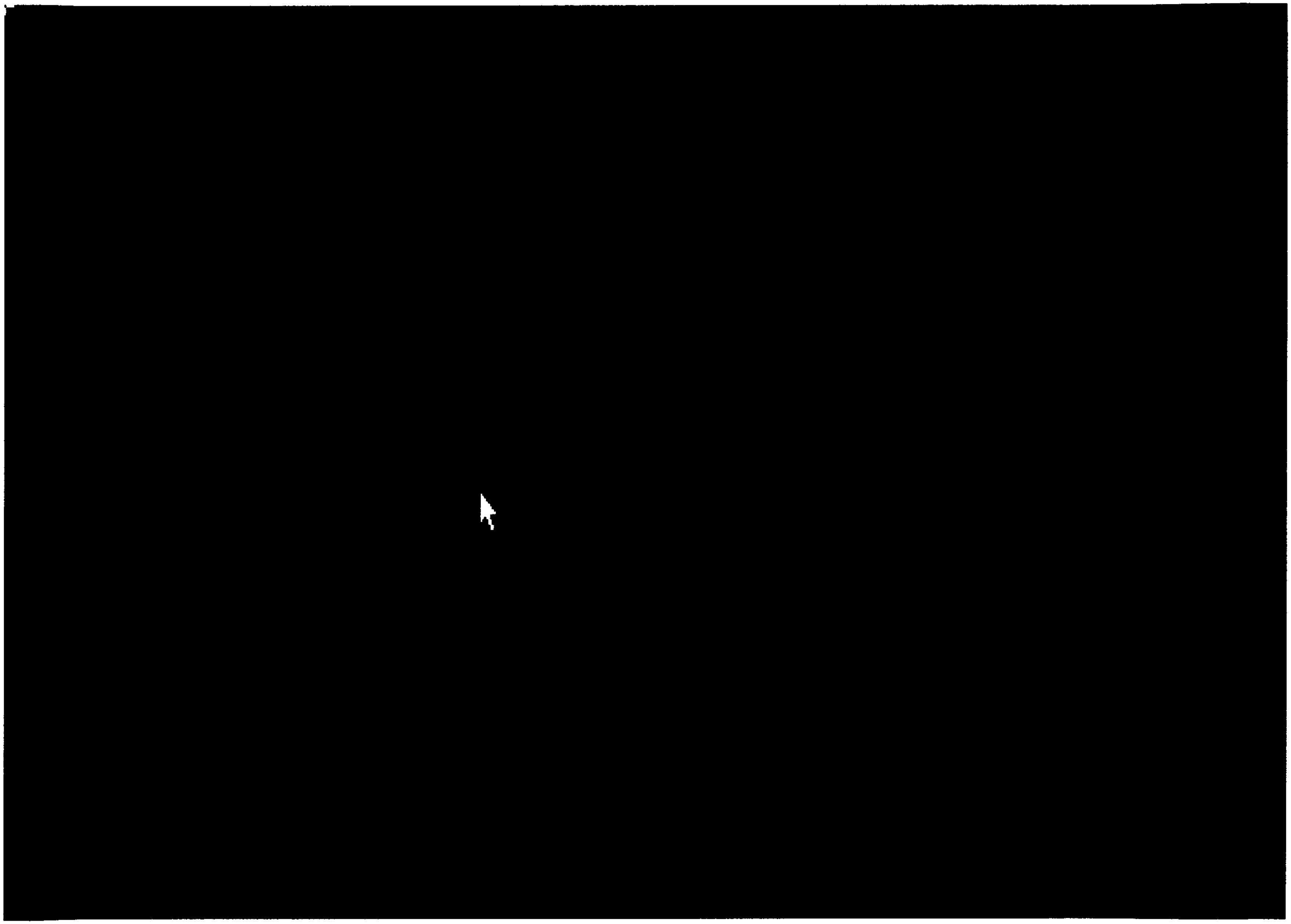

Figure 11. Main menu options

The navigation through the functionality of the package was designed using a varied mixture of menus and prompts. Selections from the menus are accomplished using a mouse-cursor tracking system. Three levels of menus are included. The main menu (menu level 1) options (Figure 11) are described as follows.

- **Display Maps** -- This option allows the user to display all VirGIS-formatted data layers in a color screen. The themes include:
  - Stream network map;
  - Stream order map;
  - Elevation map;
  - Soils map;
  - Landuse map;
  - Preliminary stream coding map;
  - Final stream coding map;
  - Computer generated sub-watershed map; and
  - Hydrologic response unit (HRU) map.

The map display option allows the user to view and inspect maps and to identify the maps that are needed for an analysis.

- **Search Files** -- This option allows the user to search data files by file name extension. A second-level menu for this option displays all file types. Once the user selects a file type, a third-level menu displays all existing files with the type selected and allows the user to list the ASCII files on the screen.

- **Edit maps** -- This option allows the user to create or edit VirGIS-formatted map files. For landuse and soil maps, this option provides the user with the possibility of editing attribute list files. A detailed description was given in the section titled Map Editor.

- **Create Rainfall Distribution Data** -- This option allows the user to edit or create rainfall distribution data by using either recorded rainfall data or design storm event. A detailed description is given in section titled FESHM required input data preparation, Data Group 2. A second level menu for this option allows the user to choose from recorded data and design storm data. For each option, the user only needs to respond to the prompts through the keyboard.

- **Create Program Control Data** -- This option allows user to enter program control output and simulation control options. A detailed description for these requirements was given in the section titled FESHM required input data preparation , Data Group 1 and Data Group 5.

- **Computer-delineated sub-watershed** -- This option allows user to create sub-watershed boundaries (element) map, routing matrix, overland and channel topographic parameters needed for FESHM simulations. The map databases needed for this option are stream order, stream network and elevation maps. A second-level menu includes the following options:

  - Select input data layer file names;
  - Preliminary stream coding (Program STREAM);
  - Final stream coding (program DISCRETE);
  - Sub-watershed delineation (program SUBSHED); and
  - Return to main menu.

- **Select Drainage Area** -- This option allows the selection of the drainage area for the conduction of runoff simulations. When this option is selected, a second-level menu displays the following possible datasets from which the drainage area can be selected:

  - Selected from entire Richmond County,
  - Select from Haynesville quadrangle,
  - Select from xx .... quadrangle,

These options are provided for the users to select drainage areas from relative small area in order to speed up the drainage area selection procedure. If a quadrangle is selected, utility program EXTRACT is used to extract the data from the county data file. After the area is selected, the sub-watershed map for this area is displayed on the screen. The mouse is then activated to allow the user to pick-up the the down-stream node of the drainage area. The routing matrix developed from program DISCRETE is used to identify all up-stream elements (the influencing area) of the selected down-stream node. Then the area map will be copied and reduced to the lower-right corner of the screen, while the drainage area map (influencing area map) will be enlarged and mapped on the main 480 x 480 pixel screen area with all the non-influencing elements painted a white color.

- **Storm water runoff simulation** -- This option allows the user to conduct the FESHM simulation based on the drainage area selected in the preceeding option. If this option is selected, program HRU, EFFHRU and FESHM will be executed in sequence. A second-level menu then will allow the user to select the mode for the FESHM simulation based on the

- Stand alone mode,
- VirGIS database mode.

When the stand alone mode is selected, a third-level menu will allow the user to examine Group 1 - Group 8 data files. When these data files are not complete, then the user can exit and prepare the data files before returning back to this option to execute the FESHM simulation. For the VirGIS database mode, a third-level menu will allow the user to examine Group 1, 2, 5, 6, 7, and 8 data files and the input data files for programs HRU and EFFHRU, soil map, landuse map, soil attribute list and landuse attribute list. If some files are not complete then the user can exit and select other options to correct and/or create the required data files. When all files are ready the programs can be executed. During program execution, a message is displayed on the screen to inform the user that execution is in progress.

- **Display Runoff Hydrographs** -- This option allows the user to display stormwater runoff simulations. To provide the capability of comparing simulation results from different input data or from different locations within the same simulation, multiple hydrograph displays can be displayed. A second-level menu gives the user options for displaying the runoff curve of the newest simulation or displaying the runoff curve from the previous simulation. When the newest simulation option is selected, the drainage area map is displayed and the mouse activated. The user then can use the mouse to select the appropriate channel or overland element for which the simulated discharge hydrograph will be displayed. When the second option is selected, a third-level menu will display names of all previous runoff simulation files. The user then can select the appropriate file for which the runoff hydrographs are to be displayed. The corresponding drainage map for the selected simulation will be displayed and the mouse activated so that the user can select the appropriate overland or channel elements from the drainage map for displaying the newest simulation. To avoid memory problems resulting from excessive simulation files, an erase file option provided in the second-level menu can be used to discard the existing runoff simulation files that are no longer needed. A multiple runoff simulation curve display is shown in Figure 12.

- **Exit** -- This option allows the user to exit to MS-DOS.

4.0 SUMMARY

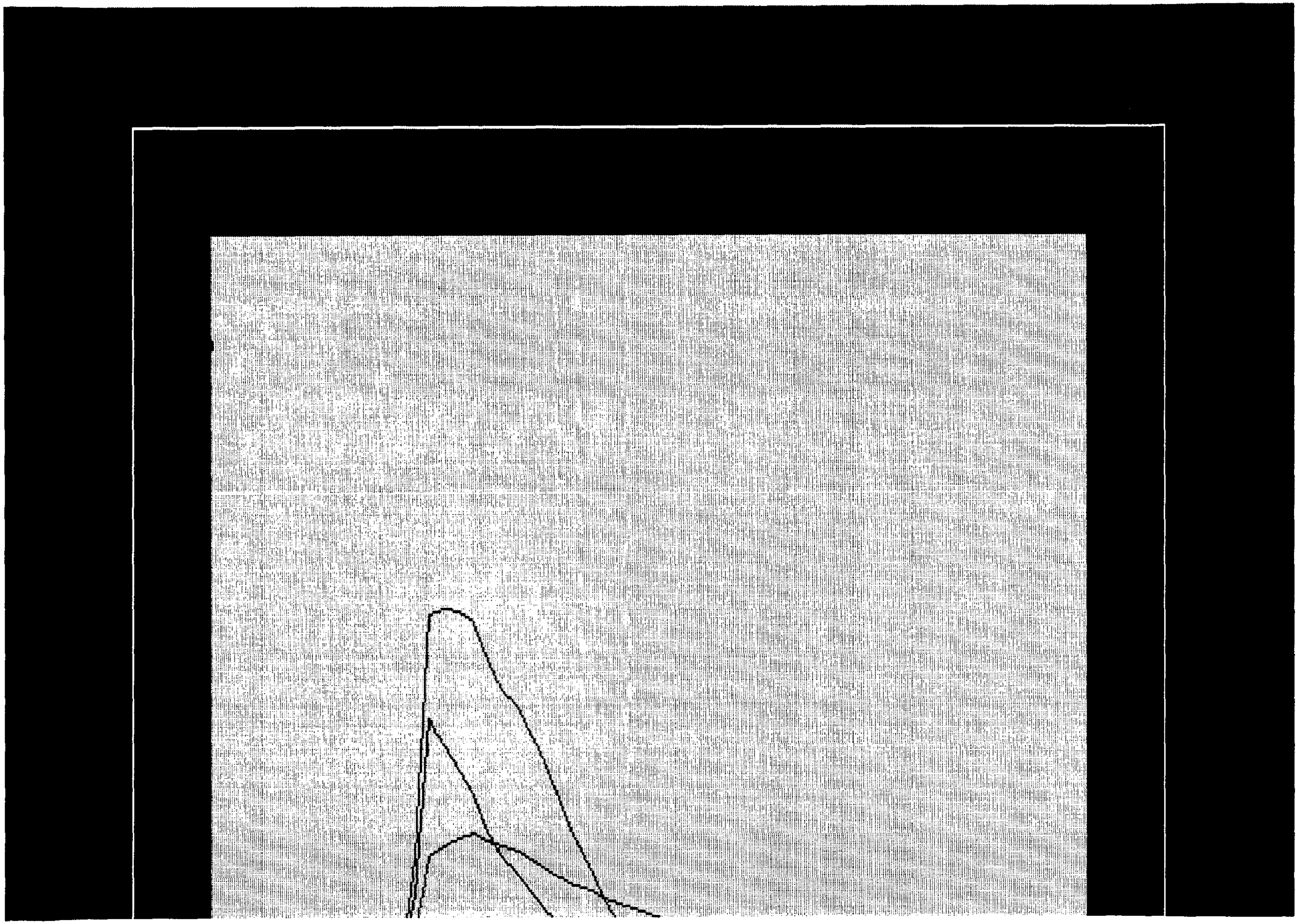

Figure 12. Display of multiple hydrographs generated by FESHM

A Hydrologic Modeling System was successfully developed and implemented on a PC. The HMS consists of a series of modules linked via a system of menus that provide navigation through the functionality of the package.

A major effort was expended to overcome problems associated with creating the extensive databases usually required by distributed parameter hydrologic models. The principal issues involved automating the selection of topographic and soil.landuse related characteristics, keyboard entry of program control instructions and designing a linkage to provide access to all components of the system within the same computing environment.

A procedure was developed to discretize the stream segments to a sub-watershed level (as required by FESHM) based on tributaries and confluences determined from center-line vectors of a stream-network map. A raster scanning scheme was used with Digital Elevation Model (DEM) type data to determine cell gradient, direction and relief from which the contributing area for a given reach was defined. The procedure also provided a rapid method for determining element flow length, slope and area.

A map editor was designed and developed to provide a simple procedure for updating and/or modifying map or attribute files. Navigation through the system is accomplished with a rich set of menus and prompts.

Tasks not fully implemented and planned for the next update include the following:

- Automated estimation of landuse and soil type related parameters;
- Design storm option for describing the rainfall distribution;
- Entry of user defined watershed delineation in lieu of automated sub-division and followed by automated selection of topographic parameters as currently supported; and
- Direct linkage between OSU-MAP, digitizer workstation and HMS package;

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